



## **Energy Efficient Cryogenics**

### **TC67\_JWG Meeting**

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**Montargis, France**

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# Energy Efficient Cryogenics

## *Overview of Technology Focus Areas and Capabilities*

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The Cryogenics Test Laboratory, NASA Kennedy Space Center, works to provide *practical solutions to low-temperature problems* while focusing on long-term technology targets for the *energy-efficient* use of cryogenics on Earth and in space.



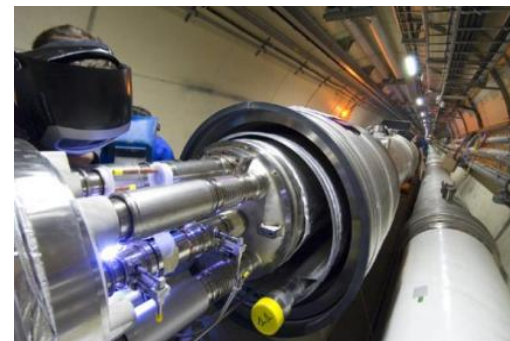
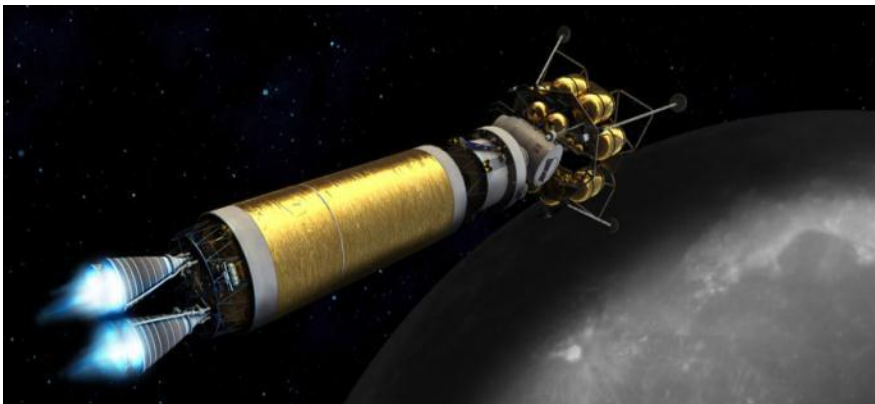
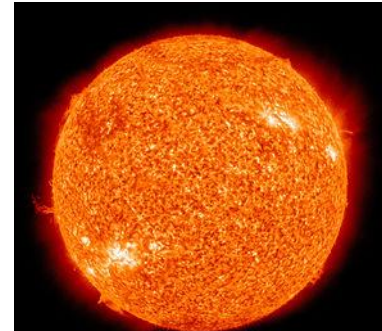
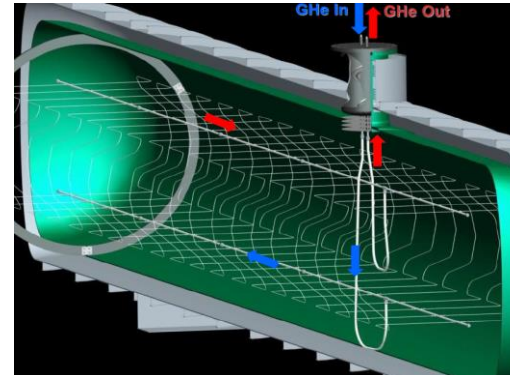
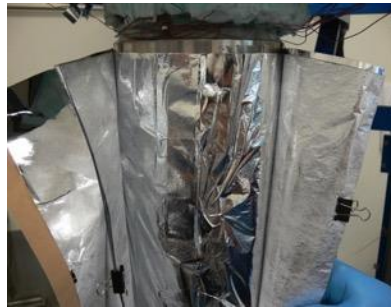
*Space launch and exploration is an energy intensive endeavor;  
cryogenics is an energy intensive discipline.*

# Energy Efficient Cryogenics

- ✓ **C**ost-Efficient Storage & Transfer on Earth
- ✓ **M**ass-Efficient Storage & Transfer in Space
- ✓ **L**ow-Temperature Materials & Novel Applications

## Cryogenics Enables:

- ✓ Propulsion
- ✓ Power
- ✓ Life Support
- ✓ Science
- ✓ Manufacturing
- ✓ Testing



The *Cryogenics Test Laboratory, NASA Kennedy Space Center*, is a unique community for research, development, and application of cross-cutting technologies to meet the needs of industry, government, and research institutions.

Technology focus areas include:

- ✓ *Thermal insulation systems*
- ✓ *Integrated refrigeration systems*
- ✓ *Advanced propellant transfer systems*
- ✓ *Novel components and materials*
- ✓ *Low-temperature applications*



*Cryogenics is about two things:*

- 1) using low-temperatures to do something useful,*
- 2) storing something in a small space (energy density).*

# Connections

- ✓ Florida Academics: UCF, FTU, USF, UF, FSU, and ERAU
- ✓ Federal Agencies: DoD, DoE, DHS
- ✓ National Institute of Standards (NIST): Boulder and Gaithersburg
- ✓ National Laboratories: Oak Ridge, Jefferson, Fermilab, Los Alamos, Livermore
- ✓ NASA Centers: MSFC, GRC, LaRC, GSFC, JSC, SSC, ARC, JPL, WSTF
- ✓ Industry Partners: Aerospace; General Industry; High Energy Physics
- ✓ Cryogenic Society of America (CSA)
- ✓ Cryogenic Engineering Conference (CEC) and International Cryogenics Materials Conference (ICMC)
- ✓ Space Cryogenics Workshop (SCW)
- ✓ International Cryogenic Engineering Conference (ICEC)
- ✓ International Institute of Refrigeration (IIR)
- ✓ American Institute of Aeronautics and Astronautics (AIAA)
- ✓ ASTM International (ASTM)
- ✓ International Standards Organization (ISO)



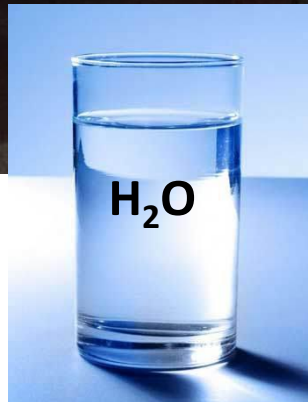
*Success in cryogenics has always been defined as a healthy triangle of interaction among research, industry, and training.*



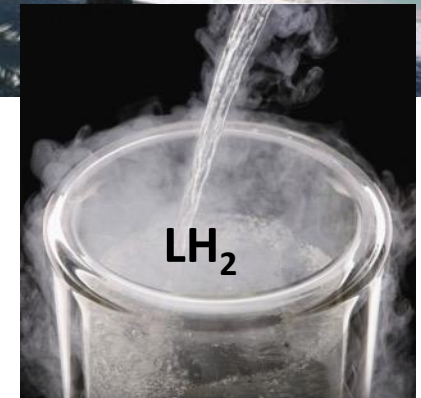
# Preservation of the Cold



$\Delta T = 500\text{ }^{\circ}\text{F}$



$\Delta T = 500\text{ }^{\circ}\text{F}$



# Technical Consensus Standards for Thermal Insulation Systems

- To help meet the today's needs and further the possibilities for future gains in *global energy efficiency*, cryogenic insulation standards are being developed.
- Under ASTM International's Committee C16 on Thermal Insulation, two new standards were published in 2014:
  - ASTM C1774 - *Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems*
  - ASTM C740 – *Standard Guide for Evacuated Reflective Insulation in Cryogenic Service*





# Thermal Insulation Systems Development and Materials Research

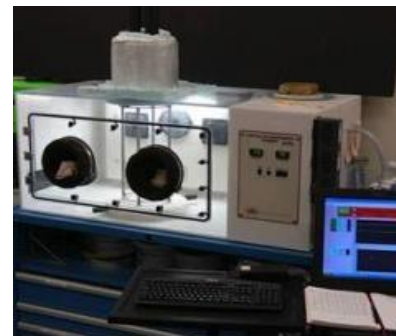
- Foams: Polystyrenes (Styrofoams), Polyimides, Polyurethanes
- Aerogels: (Space Technology Hall of Fame and R&D 100 winner)
  - Flexible blanket [Aspen Aerogels, Inc.]
  - Particles and expansion packs [Cabot Corp.]
  - Polymer cross-linked aerogels (X-aerogels) and experimental
- Bulk-Fill Powders: Glass bubbles, Perlites, Aerogels
- Multilayer insulation (MLI):
  - Aluminum foil and micro-fiberglass paper
  - Double-aluminized Mylar and polyester non-woven fabric
  - Double-aluminized Mylar and polyester netting

# Thermal Insulation Systems Development and Materials Research (cont.)

- Layered composite insulation (LCI) systems: (patents and patents pending)
  - High vacuum or soft vacuum applications (LCI), or,
  - Non-vacuum, external environment applications (LCX)
- Vacuum insulated panels (VIP) with glass bubbles
- AeroPlastics and AeroFiber composite panels (patents and patents pending)
- AeroFoam composites for insulation, cryofuel storage, or cold batteries (patents)
- Novel smart, multifunctional composites: (patents pending)
  - Insulating – Conducting Composites (ICCs)
  - Passive-Acting Switchable Composites (PSCs)
  - Low-Temperature Shape Memory Alloy Systems for Broad-Area Thermal Management

# Cryostat Insulation Test Instruments

- Cryostat-100, Cylindrical – Absolute
- Cryostat-200, Cylindrical – Comparative
- Cryostat-400, Flat Plate – Comparative
- Cryostat-500, Flat Plate – Absolute
- Macroflash (Cup Cryostat), Flat Plate - Comparative
- Cryogenic Moisture Uptake Apparatus
- Transient Thermal Tester
- 1000-liter Tank Cryostat (LH<sub>2</sub> or LN<sub>2</sub>)
- Cryogenic Pipeline Test Apparatus
- Patents:
  - *Methods of Testing Thermal Insulation and Associated Test Apparatus*, US Patent 6,742,926
  - *Multi-purpose Thermal Insulation Test Apparatus*, US Patent 6,487,866
  - *Thermal Insulation Testing Method and Apparatus*, US Patent 6,824,306
  - *Insulation Test Cryostat with Lift Mechanism*, US Patent 8,628,238 B2
  - *Thermal Insulation Testing Method and Apparatus*, US Patent 6,824,306
  - *Insulation Test Cryostat with Lift Mechanism*, US Patent application, US20140079089 A1
  - Additional patents pending



# Liquid Oxygen Ground Operations Demonstration Project (GODU-LO<sub>2</sub>)

## Objectives:

- Rapid propellant (cryofuel) loading concept demonstrations.
- Autonomous control and data monitoring system development.
- Testbed for development of many technologies and innovations, such as:
  - Fault tolerance of failed control valves and sensors.
  - Software to monitor overall health and status of propellant loading system.
  - Component (valves and pumps) sealing system designs.
  - Cryogenic composite tank structural/thermal monitoring.
  - Novel sensors applications and use in real world environments.



*Overall view of the Simulated Propellant Loading System located at the CryoTestLab*



## Features:

- Up to 800 GPM flow rate and 225 PSI.
- Four cryogenic pumps are fed from a 6,000 gallon liquid nitrogen supply tank.
- Pumps have varying flow capacities from 25 up to 450 GPM.
- Complexity and component count is comparable to full scale launch pad transfer system
- Modular and re-configurable for a wide range of different vehicle or R&D requirements

# ISO Work – LN<sub>2</sub> Vapor Work

## Objective:

- Evaluate the effects of LN<sub>2</sub> vapor on “simulated insulation sample”.

## Test Hardware

- Various “nozzles”
- Data acquisition system (DAQ)
- 6,000 gallon LN<sub>2</sub> storage tank
- Simulated insulation sample (enclosure)





# ISO Work – LN<sub>2</sub> Vapor Work (cont)

## Test Hardware

- Simulated insulation sample (enclosure)



Sample enclosure

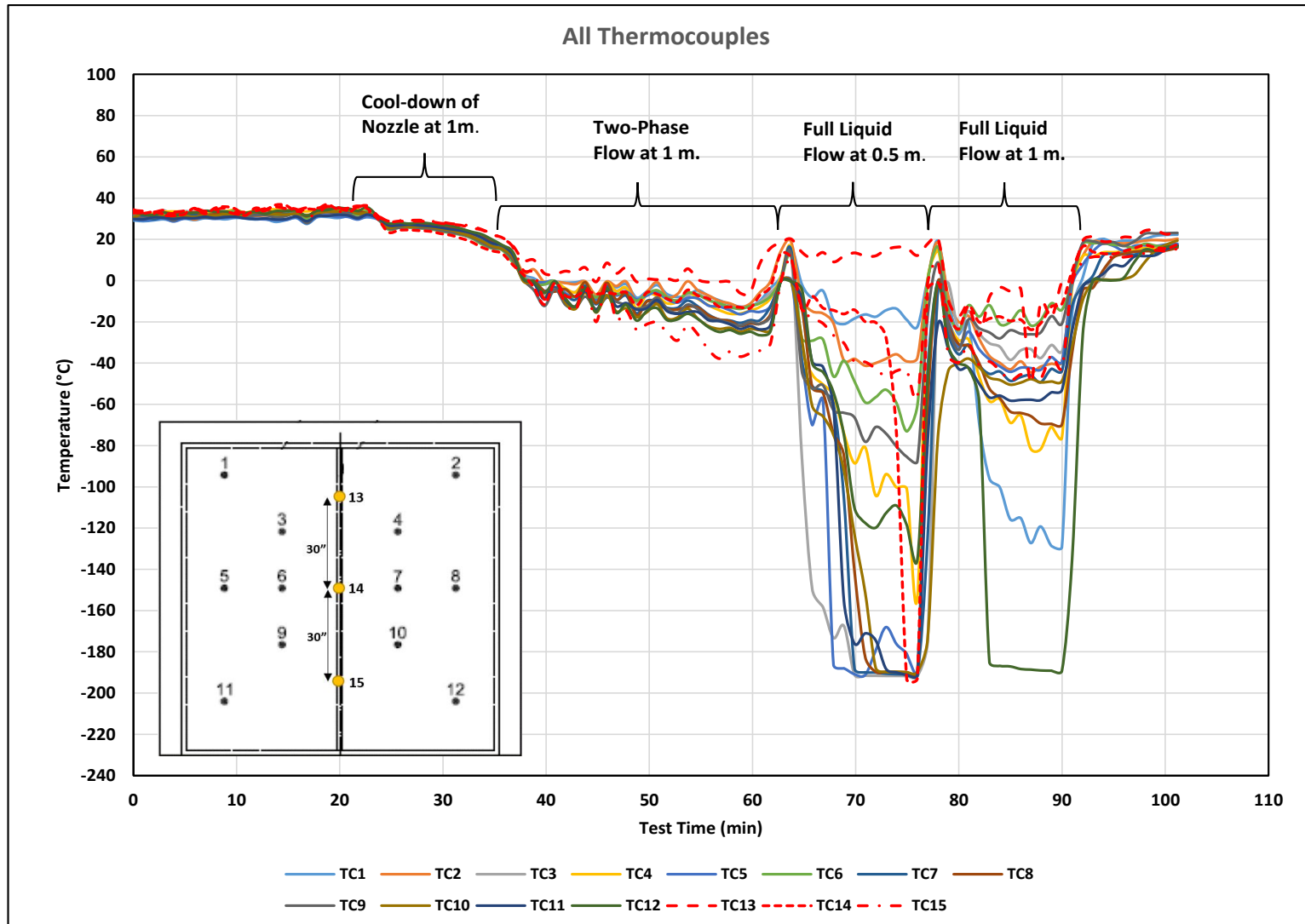


Test run (vapor cloud)



Test run (1m distance)

# ISO Work – LN<sub>2</sub> Vapor Work (cont)



# Conclusion

- Cryogenics is globally and fundamentally linked to energy generation, storage, and usage.
- Two keys to safe and cost-efficient (on mass-efficient) storage, transfer, and application of cryogenics:
  - Integrated refrigeration systems technology (active systems)
  - Thermal insulation systems technology (passive systems)
- New high efficiency designs, methodologies, and materials (active + passive) are being developed.
- Vital collaborations are with industry and academic research institutions for a wide range of applications, both commercial and government.

*Through measurement to knowledge; through knowledge to product.*



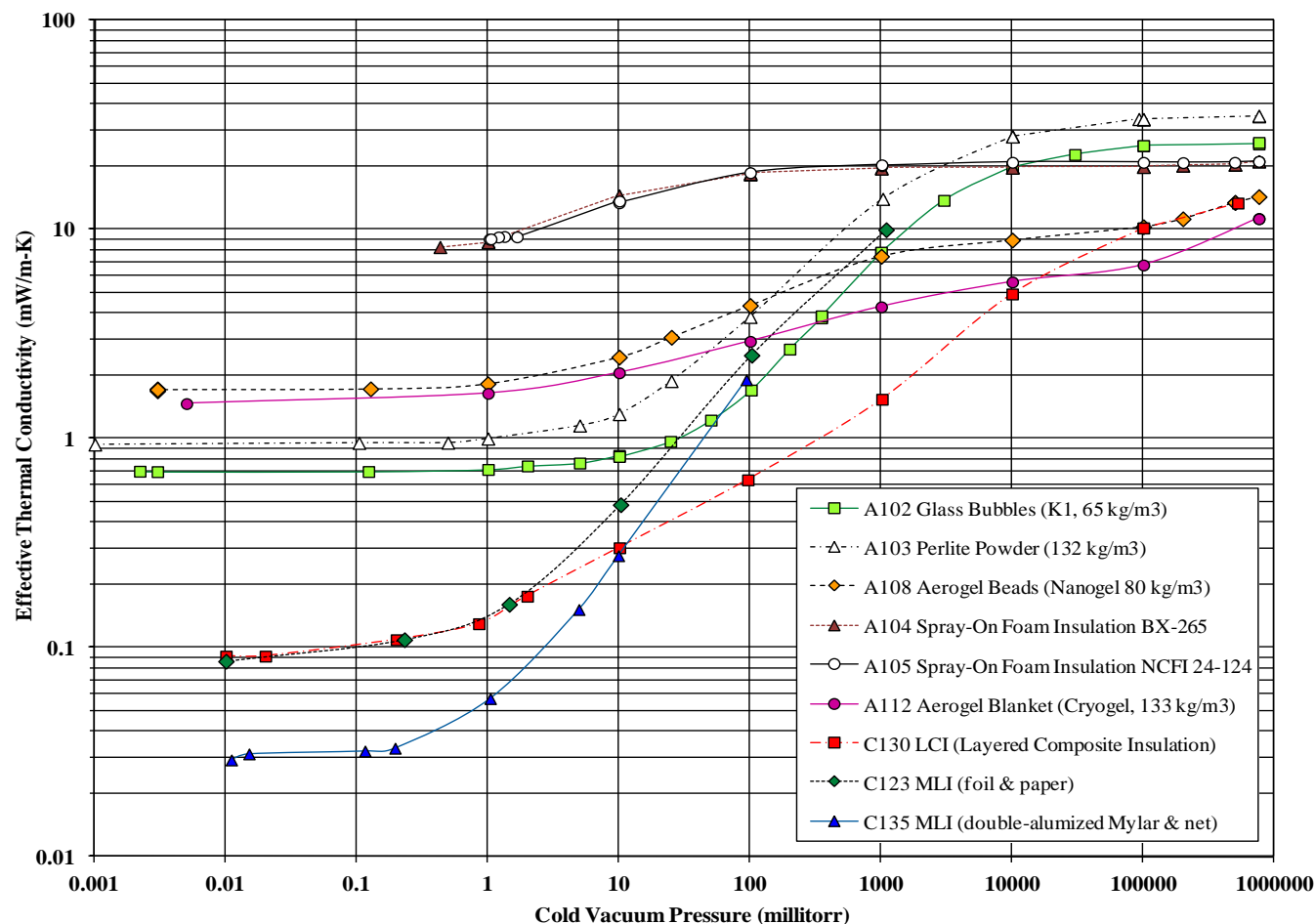
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# Thermal Performance of Various Cryogenic Insulation Materials



Examples of the variation of effective thermal conductivity ( $k_e$ ) with cold vacuum pressure are shown for different cryogenic insulation systems. The boundary temperatures are approximately 78 K and 293 K, the residual gas is nitrogen, and the total thicknesses are typically 25-mm.<sup>1</sup>

<sup>1</sup>Fesmire, J. E., Coffman, B. E., Meneghelli, B. J., Heckle, K. W., "Spray-On Foam Insulations for Launch Vehicle Cryogenic Tanks," Cryogenics, doi:10.1016/j.cryogenics.2012.01.018.



# Ground Operations Demonstration Unit for Liquid Hydrogen (GODU-LH<sub>2</sub>)

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NASA Kennedy Space Center

# Integrated Refrigeration Objectives

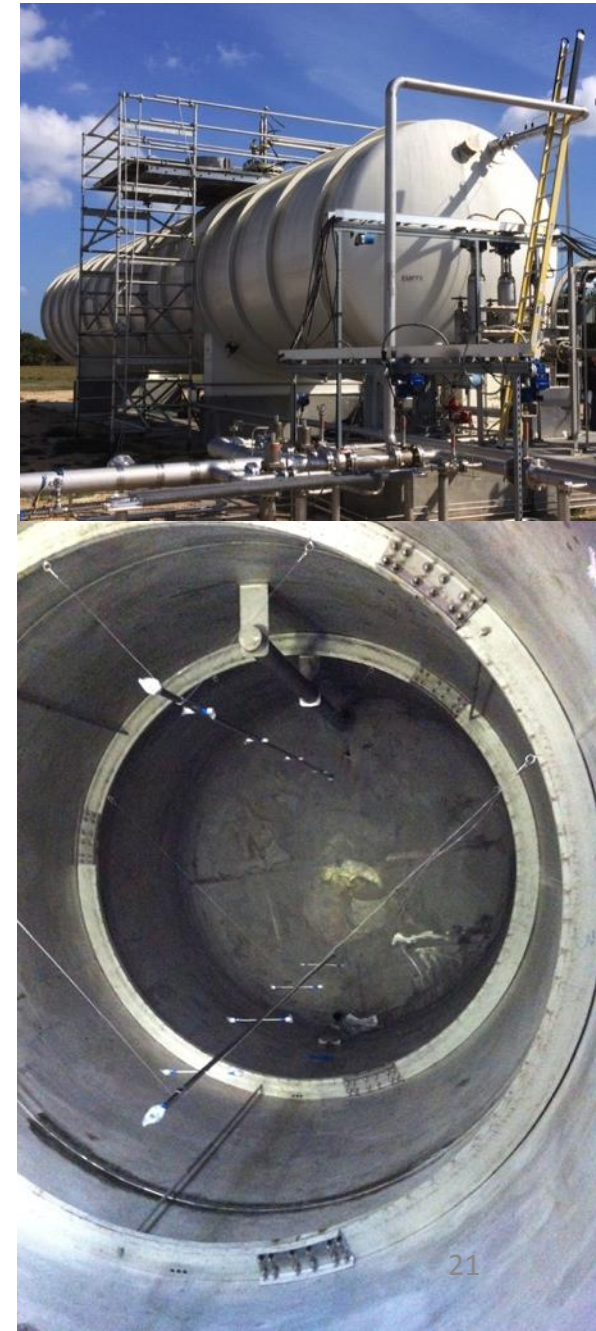
## GODU-LH<sub>2</sub>

- Demonstrations:
  - ✓ Zero loss storage and transfer of LH<sub>2</sub> on a large scale
  - ✓ Hydrogen liquefaction using close cycle helium refrigeration
  - ✓ Hydrogen densification in storage tank and loading of flight tank
- Secondary objectives:
  - ✓ Creating a densified hydrogen servicing capability
  - ✓ Maintaining critical cryogenic design and operations skills
  - ✓ Demonstrating low-helium usage operations
  - ✓ Validating modern component technologies
- Potential Advantages of IRAS LH<sub>2</sub> Systems:
  - ✓ Cost savings (less boiloff)
  - ✓ More autonomy in operations (less downtime)
  - ✓ Improved safety and reliability (enthalpy margin)



# Integrated Refrigeration and Storage (IRAS) System for GODU-LH<sub>2</sub>

- Vacuum-Jacketed Tank Features:
  - 125 m<sup>3</sup> (33,000 gal) capacity, 22 m (70 ft) length, 3 m (10 ft) diameter
  - Vacuum-jacketed with foil/paper MLI
  - Modified 600-mm diameter manway for helium and instrumentation feedthrough
  - Internal stiffening rings for sub-atmospheric pressure operation
- Heat Exchanger Features:
  - Cold helium, end-to-end flow balanced
  - Modular self-supporting system with 300 m of 6-mm diameter stainless steel tubing
  - Cold helium in-line process temperature sensors (4 silicon diodes)
  - Three temperature rakes to measure vertical and horizontal gradients (20 silicon diodes)



# GODU-LH<sub>2</sub> Future Uses

- LH<sub>2</sub> Integrated Refrigeration and Storage system is fully operational at Kennedy Space Center.
- Upon completion of the GODU-LH<sub>2</sub> project, the system will be available for other uses:
  - Servicing on upper stages or test stands with densified hydrogen
  - Hydrogen distribution applications
  - Cryostat-900 and high efficiency transfer lines
  - Fuel cell and electrolysis research
  - Spacecraft loading ground support equipment
  - Superconductivity applications

# Advanced Cryogenic Storage & Transfer

- End-to-end system architectures for rapid and reliable operations
- Composite materials development with real-world prototype combined functional testing: structural, vibration, and thermal.
- Autonomous control and system health monitoring
- Modular, semi-flexible piping systems
- Zero-loss transfer of Liquid Hydrogen
- Supporting Technology for Safe Operations (NASA-KSC Patents):
  - Color-changing tape for hydrogen gas leak detection
  - Aerogel blended polymers (AeroPlastic) for sealing components
  - Aerogel foam composites (AeroFoam) for cryogen storage
  - Aerogel fiber panel composites (AeroFiber) for structures and thermal protection systems
  - Layered composite insulation system for extreme environments (LCX)





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